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An Efficient Automatic Water Sprinkler Design for Operate in Dust Environment

Akshatha Manjunath[1] and Kavyashree Muldabeedu Kanthraju[2,*]

[1]M. Tech in Industrial Electronics, JSS Science and Technology University, Mysuru, India
[2]Department of Electronics and Communication Engineering, JSS Science and Technology University, Mysuru, India

([*]Corresponding author's e-mail: kavyashreemk@sjce.ac.in)

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Abstract

The dust density within the environment must be continuously monitored in open cast mines. Water sprinklers are used to suppress the dust in mining field. Water sprinklers capacity used are of 28,000 and 70,000 L. These conventional water sprinklers comprise of 4 kinds of sprinkling thus the operator must choose and actuate any 1 type of sprinkling which is appropriate to suppress the dust. The traditional water sprinkler is worked physically by the operator that is operator turns on the type of sprinkling dependent on the dust seen by him. This technique does not completely suppress the dust and it's not accurate. Furthermore, water is squandered if the dust density is according to the directions given by central pollution control board. Supportive to the above background, it is necessarily essential to actualize the water sprinkling system automatically which measures the dust density contained in mine atmosphere and likewise module will consequently actuate the sprinkling so as to suppress the dust in the environment. This technology is compatible to inbuild display for continuous monitoring of dust concentration also the system has both auto/manual operation. At the point when the dust concentration crosses the admissible value automatically system will activate solenoid driver to start out the sprinkling activity. Therefore, the designed dust monitor module is employed to implement an automatic system, utilizing advanced technology to monitor the density of fine dust particles in the mining environment & accordingly the sprinkling operation is actuated with minimal human intervention.

Keywords: Automation, Continuous monitoring, Dust density, Dust monitor module, Solenoid driver

Introduction

The method of getting coal or different minerals from a mine is depicted as Mining. Mining as characterized by the Oxford dictionary is the procedure or industry of procuring coal or different minerals from a mine. Mining is the process of extraction of raw materials from the earth. Coal is one among the mining products in that process [1]. Dust is one of the most significant natural hazards which are associated along with the numerous technical hazards which takes place during the mining activity [2]. The average mine worker is exposed to the intense underground condition in mining field which winds up in bring about a physical issue or it might cause death. Logical investigations have demonstrated that exposure to particle in the dusty environment condition causes development of chronic bronchitis, increased respiratory manifestations, and so forth. Coarse particles PM10 and fine particles PM2.5 can cause the greatest issue since they can get profound into the lungs [3,10]. One of the perspectives with respect to airborne dust is the spreading of combustible coal dust and its deposition in the working which may cause explosion [13]. Deposition of coal dusts in the mine have been the main reason to the cause of explosions and in turn mine calamities. Preventive measures aimed at increasing occupational safety as well as awareness of mine work force are still improving [2,9].

Dust is one of the most significant health and safety risks in numerous fields, for example, construction, concrete plants and mining industry. One of the primary sources of health and safety risk in surface and underground coal mines is coal dust. In any coal mine operations, coal dust monitoring and controlling are the basic measures [7]. Exposure to dust particles can prompt to genuine medical issues. Logical examinations have connected particle exposure to development of diseases like bronchitis, increased respiratory symptoms, and so on [3,10]. Specifically, dust particles under 10 μm in size

(respirable) are a wellspring of annoyance and these easily enters the lower zone of the respiratory organ [3,7]. Fine dust particles are verified to considerably have an influence on human wellbeing, as particles can without much of a stretch infiltrate the body's respiratory system. An incurable lung infection that is pneumoconiosis is also caused by exposing human respiratory system to the dust for long period. Truth be told, the impacts of exposure to fine dust in large concentration run in severity from asthma to even lung cancer that is respiratory organ malignant growth [5,8]. Inhaling respirable coal dust causes some of the most hazardous illness such as Coal Workers Pneumoconiosis (CWP) also called as deadly black lung disease, progressive massive fibrosis (PMF) and chronic obstructive pulmonary (COP). Coal dust explosions is another hazard to coal mining activities [3,7]. Hence, the environment dust density has to be continuously monitored [4].

Wide scope of instruments for dust density measurement is available on the market, however the majority of them are either very costly or can't be effectively utilized as a compact and portable unit [10]. Along with harming underground coal miner health coal dusts also causes explosion when they are in certain specific concentration [11]. Thus, it is very imperative to measure dust concentration in real time precisely [14]. In this manner, the dust density in the environment should be persistently monitored in open cast mines. In this manner, thus, a dust monitoring system is essential in any surface and underground coal mining operation to keep up the wellbeing and safety of workers [9]. This paper presents the design and development of automatic dust monitoring module which is used in automating the water sprinklers manufactured at BEML. The main features of the system are ease use, low cost and reduces the human intervention and thus the sprinkler operates accurately and also prevents loss of excess water. The proposed system consists of 4 main subsystems. They are dust sensor, 4 channel relay, LCD Display and PIC microcontroller.

Materials and methods

Problem statement

WS28-2 water sprinkler is specially designed for control of dusty environment on open cast mines. The water tank capacity is 28,000 L. The vehicle can sprinkle 14 m wide in single pass.

Figure 1 Water sprinkler WS28-2.

In emergency, WS28-2 can also be utilized as a standby unit for firefighting. Conventional water sprinkling method is manually operated by the operator. This water sprinkling vehicle consists of 4 types of sprinkling methods that is Pressurized sprinkling at rear, Pressurized sprinkling at front, Gravity sprinkling and MIST sprinkling. Based on the amount of dust seen by the operator he has to choose the type of sprinkling which is suitable to suppress the dust in open cast mines. This conventional method is manually operated by the operator which does not completely suppress the dust and it is not accurate. And furthermore, water is squandered if the dust density in environment is as per the directions given by central pollution control board. Based on the above background, it is necessary to implement the automated water sprinkling system. With the help of advanced methods, which ideally select the type of sprinkling based on the dust density. With help of dust sensors, system could automatically actuate the

sprinkling operation based on the dust density in order to maintain dust levels as per directions given by CPCB.

Components used for implementation of system

Automatic dust monitoring module comprises 4 main systems they are dust sensor, PIC microcontroller, 4 channel relay and LCD display. Dust sensor is interfaced to PIC microcontroller where the data of the dust concentration is transmitted to microcontroller from dust sensor. Microcontroller is also connected to LCD display and 4-channel relays. Microcontroller is assembled on Printed Circuit Board (PCB) from which the other 3 systems are connected and by assembling components on PCB, system has become compact in size and also in case of any damage it is very easy to diagnose and replace the components. Automatic dust monitoring module comprises 4 main systems they are dust sensor, PIC microcontroller, 4 channel relay and LCD display. Dust sensor is interfaced to PIC microcontroller where the data of the dust concentration is transmitted to microcontroller from dust sensor. Microcontroller is also connected to LCD display and 4 channel relays. Microcontroller is assembled on Printed Circuit Board (PCB) from which the other 3 systems are connected and by assembling components on PCB, system has become compact in size and also in case of any damage it is very easy to diagnose and replace the components.

PIC microcontroller

PIC is a group of microcontrollers made by Microchip Technology. Firstly, PIC was alluded to Peripheral Interface Controller, and is by and by extended as Programmable Intelligent Computer. PIC microcontroller utilized in this system is PIC16F877A. The PIC microcontroller PIC16F877A is one of the most eminent microcontrollers in the industry. Totally it has 40 pins and out of which there are 33 pins for input and output. It comprises of 2 8-bit and 1 16-bit timer. **Figure 2** shows the pinout diagram of PIC16F877A. This microcontroller is extremely advantageous to use. One of the primary favorable advantages is that it can be write-erase as many times as possible since it utilizes Flash memory technology.

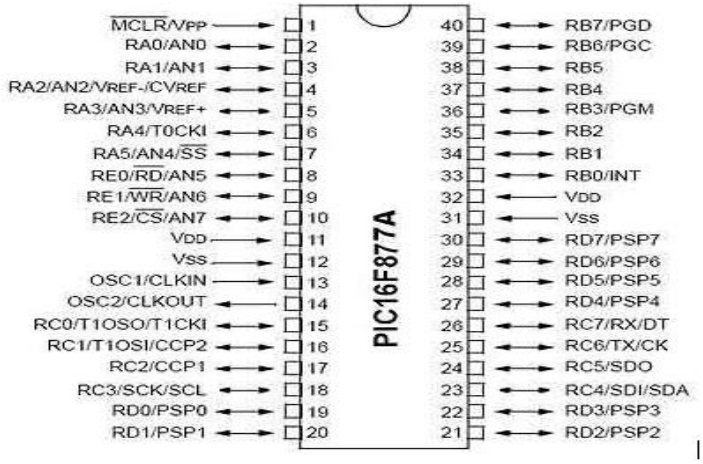


Figure 2 Pin out diagram of PIC16F877A [15].

PIC16F877A additionally have a lot of use in digital electronic circuits. Presently huge number of devices works with the application of PIC16F877A. An EEPROM is likewise included in it which makes it possible to store a portion of the data permanently. This microcontroller has some characteristics such as it has a smaller 35 instructions set, it can operate up to 20 MHz frequency. It operates between 4.2 to 5.5 volts. This controller is currently used in many fields such as remote sensing, home automation, safety and security devices and many industrial instruments [15].

Dust sensor

Dust sensors which works principle of optical are available in wide scope. But many of these sensors require an additional heating resistor which is utilized to create an air flow through the measurement chamber [16]. Moreover, this imposes some disadvantages mainly due to high power

consumption and issues with orientation of the sensor during the operation. GP2Y1010AU0F is one among the couple of optical dust sensors which work without any additional heating resistor and this makes it suitable for low-power systems [6]. The internal schematic of the sensor GP2Y1010AU0F is shown in **Figure 3**.

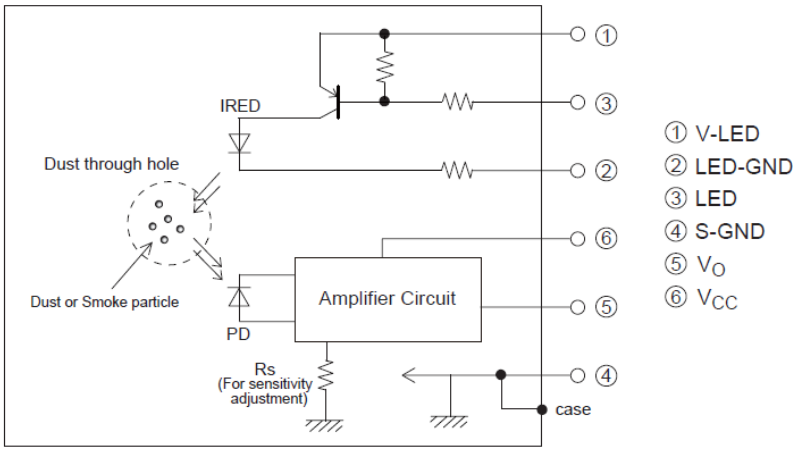


Figure 3 Internal schematic of GP2Y1010AU0F sensor [16].

The infrared emitting diode (IRED) is diagonally arranged with the phototransistor (PD) as shown in the **Figure 3** which detects the reflected light by an airborne dust. Some of the features of this dust sensor are;

1) Compact size (46.0×30.0×17.6 mm^3)
2) Current consumption is low (Icc: Max. 20 mA)
3) Photometry of only one pulse is enough to detect the presence of dust.
4) Hard to differentiate smoke from house dust
5) Sensor is Lead-free and RoHS directive compliant

Figure 4 Optical dust sensor GP2Y1010AU0F.

Output voltage which is proportional to dust density ΔV from which the dust density can be calculated is given as the difference between the output voltage Vo of the sensor and the output voltage at no dust Voc [16].

$$\Delta V = Vo - Voc \quad (1)$$

I2C 1602 Liquid crystal display module

A (16×2) LCD indicating 16 characters with 2-line display is being used in this system and it has the following features;

1) 16 characters ×2 lines display
2) Built in controllers
3) I2C Interfacing

The I2C 1602 LCD module comprises of a I2C daughter board interfaced with LCD of 2 line by 16-character display. To operate I2C interface requires only 2 data connections, +5 VDC and GND. The I2C 1602 LCD module is shown in **Figure 5** [17].

Figure 5 I2C 1602 LCD module [17].

The pinout diagram of I2C daughter board is shown in **Figure 6** which consists of 4 pins they are VCC, GND, SDA & SCL. SDA is serial data line and SCL is serial clock line which are connected to the microcontroller.

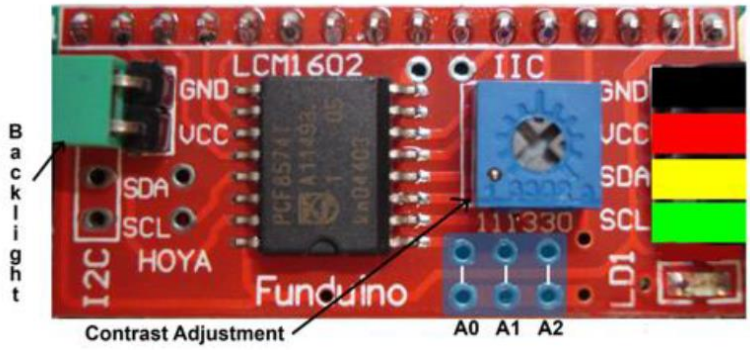


Figure 6 I2C pin out diagram [17].

Four channel relay module

Relay module with 4-channels is used in this system in order to control 4 solenoid drivers which in turn controls 4 types of sprinkling system. This module is connected to microcontroller and permits to control different apparatuses and other equipment's with large current. Some specifications of this are;

1) It is a 4-channel relay interface board, and each one needs 15 - 20 mA driver current [18].
2) Controlled by both 12 and 5 V input voltage
3) Provided or furnished with high current relay, AC250V 10A; DC30V 10A
4) Standard interface that can be controlled by microcontroller
5) Opto-isolated inputs
6) Indicates LED's for Relay output status.

Figure 7 shows the picture of 4-channel relay. The 4-output of the relay is connected to the solenoid drivers of each sprinkling system present in water sprinkler in order to control them [12].

Figure 7 4-channel relay module.

System design

The system is developed with the 4 main components mentioned above and it measures the dust density based on which the sprinkler system is automated. It consists of PIC16F877A microcontroller assembled on printed circuit board, I2C - LCD interfaced module, GP2Y1010AU0F dust sensor and 4-channel relay module. Microcontroller is connected to LCD using I2C communication, where the dust density value and the type of sprinkling currently actuated is displayed. Dust sensor is connected to the microcontroller which sends the data to the PIC based on the dust particles present in the environment. Microcontroller is also connected to the 4-channel relay module which is in turn connected to the solenoid drivers present in the water sprinkler in order to actuate the type of sprinkling operation based on the dust density.

Automatic dust monitoring module is shown in the **Figure 8**. Automatic dust monitoring module is programmed using Embedded C language and compiled in "Mikro C pro for PIC" compiler. Program can be erased and write as many times as possible since the controller has flash memory technology.

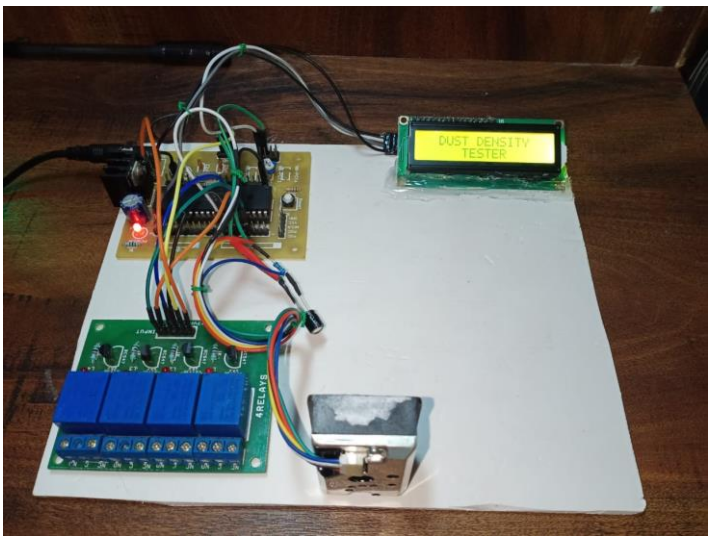


Figure 8 Automatic dust monitoring module.

Hardware design

PIC microcontroller is assembled on the printed circuit board in order to ensure connections to other 3 systems. The PCB design designed for this system is shown in the below **Figure 9**.

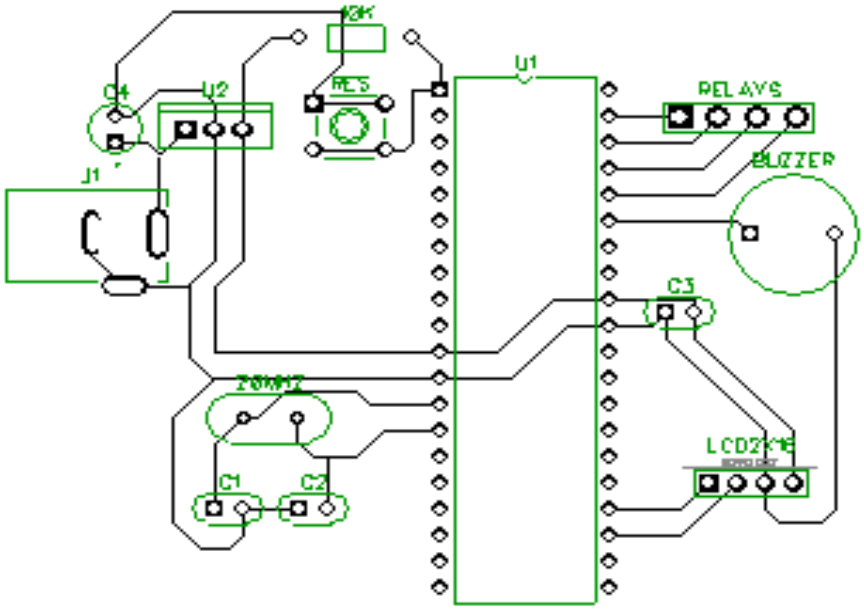


Figure 9 PCB Design of microcontroller assembling.

System gets the supply from the vehicle battery or the power supply which is 12 or 24 V. 7805 regulator is used here, which promotes compatibility to 5 V. Dust sensor has 6 pins, Vo pin which is the output pin of dust sensor sends the analog voltage signal to the RA0 pin of PIC microcontroller. This pin RA0 is used as an analog pin, it is the built-in analog to digital converter. Hence, the controller converts the analog value sent by the dust sensor to the digital for furthermore requirements. And RB0 of microcontroller is connected to the dust sensor LED pin. Using the analog voltage sent by the dust sensor, PIC microcontroller calculates the dust density which is programmed. The equation for calculating the dust density is given by;

$$calVolt = rawAdc \times (7.00 \div 1020) \quad (2)$$

$$Dust\ Density = 0.17 \times calVolt - 0.1 \quad (3)$$

Using Eqs. (2) and (3) microcontroller calculates the setted dust density value and current dust density value. The 4-channel relay consists of 6 pins where the 4 pins of microcontroller that is RB1, RB2, RB3 and RB4 are connected respectively to the 4 inputs of the relay. This relay is operated at 12V. Based on the Vout obtained by calculating as given in the Eq. (4), the microcontroller sends the signal to the corresponding channel of the relay. Microcontroller is connected to the LCD using I2C communication. I2C communication is a bus protocol which communicates through SDA (serial data) and SCL (serial clock). The data sent needs to be data synchronized using a clock bit. The data bit sent needs to be synchronized using SDA manner and SCL. SDA and SCL are connected to RC4 and RC3 pins of microcontroller respectively. Potentiometer is used to set or change the setted dust density value based on the conditions. The maximum value which is read is kept as threshold that is the setted value which needs to be set by the user using potentiometer. Based on this value it is divided into 4 stages which can be set as thresholds for each of the 4 relays to actuate. **Figure 10** shows the setted dust density value using potentiometer which is also displayed in the LCD.

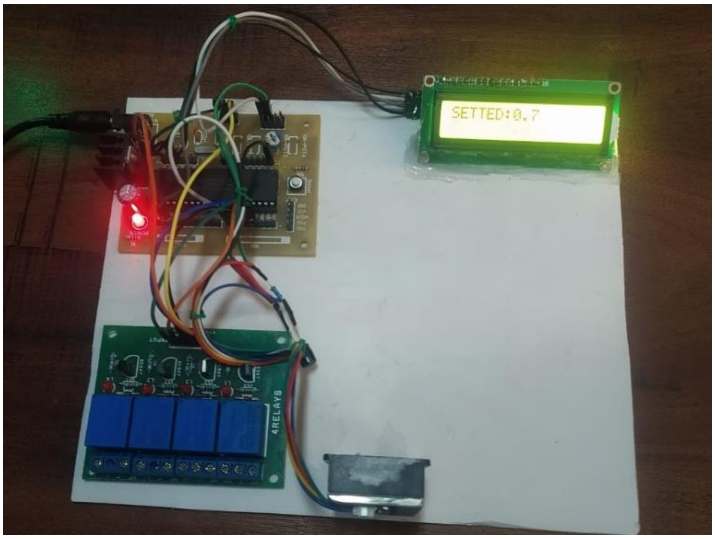


Figure 10 Setted value is set as 0.07 using pot which is displayed in LCD.

This setted value can be set by the user depending on the environment using potentiometer. The current dust density value is obtained from the dust sensor which is also displayed in the LCD along with setted value. Microcontroller calculates the difference between the current value and the setted value, obtaining the result it actuates the solenoid driver through relay where the thresholds are set to each relay. Also, the type of sprinkling which is currently being in use is displayed on the LCD for driver's knowledge. The 4 types of sprinkling present in the water sprinkler are front sprinkling, rear sprinkling, gravity sprinkling and MIST sprinkling. MIST sprinkling is preferred when the dust density is high. The equation for calculating the output voltage for relay is given by;

$$Vout = Current\ value - Setted\ value \quad (4)$$

Dust sensor continuously monitors the dust density in the environment even after 1 sprinkling system is in operation and hence, if the dust in the environment decreases or if there is no dust the sprinkler automatically stops sprinkling the water and thus also prevents loss of excess water.

Table 1 below shows the type of sprinkling actuated for the difference output voltage based on the threshold set.

Table 1 Selecting type of sprinkling based on the dust density.

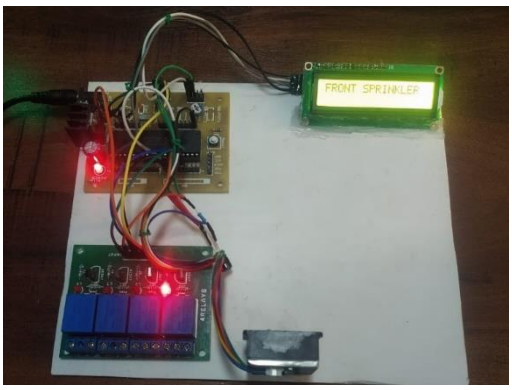
Current dust density value	**For setted dust density value = 0.07 mg/m^3**		
	Current value - setted value	**Vout range**	**Type of sprinkling**
≥ 0.82	(Current value - 0.07) mg/m^3	≥ 0.75	MIST sprinkling
≤ 0.81 & > 0.57	(Current value - 0.07) mg/m^3	< 0.75 & ≥ 0.50	Gravity sprinkling
≤ 0.56 & > 0.32	(Current value - 0.07) mg/m^3	<0.50 & ≥ 0.25	Rear sprinkling
≤ 0.31	(Current value - 0.07) mg/m^3	< 0.25	Front sprinkling

Software

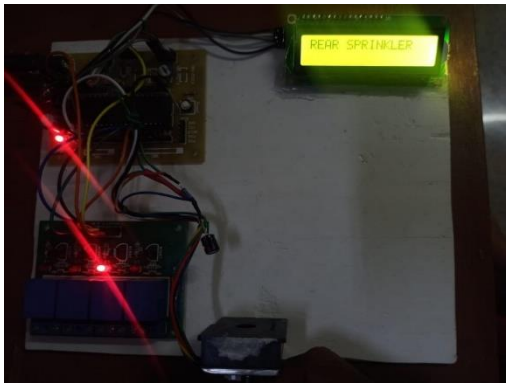
Automatic dust monitoring module is programmed using Embedded C language. It is compiled using "mikroC pro for PIC" compiler. This microcontroller has flash memory technology hence the program can be erased and write many times. The program is dumped into the PIC microcontroller using Pic kit.

Results and discussion

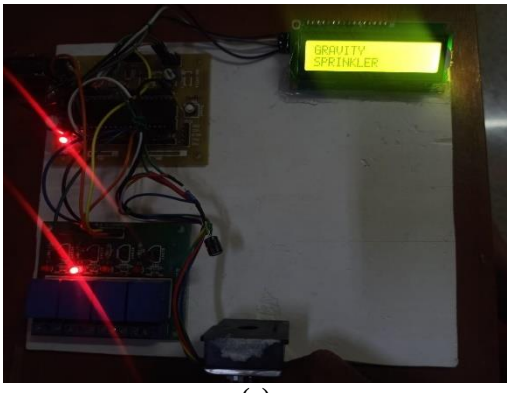
This paper presents the implementation of the automatic dust monitoring module in the water sprinklers manufactured at BEML, which are being used in mining field in order to suppress the dust in mine. **Figures 11**(**a**) **- 11**(**d**) shows the results obtained when front sprinkling, rear sprinkling, gravity sprinkling & MIST sprinkling systems are actuated respectively. That is these systems are actuated based on the current dust density. Supply to this system is given from vehicle battery. Based on the dust density in environment, module sends the signal to the specific channel of a 4-channel relay. The NO pin of each channel of 4-channel relay are connected to their respective solenoid driver's coil. Thus, this system controls the solenoid valve which in turn controls the 4 type of sprinkling system.



(a)



(b)



(c)

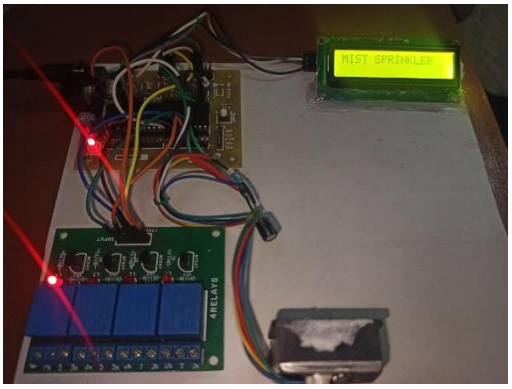


Figure 11 (a) Front sprinkling system is actuated; (b) Rear sprinkling system is actuated; (c) Gravity sprinkling system is actuated; (d) MIST Sprinkling system is actuated.

In **Figure 11(a)**, front sprinkling is actuated by sending a signal to the first channel of a 4-channel relay which is shown by glowing LED which is in front of first channel and also the sprinkling method is displayed in LCD for driver's knowledge. In **Figure 11(b)**, rear sprinkling is actuated by sending a signal to the second channel of a 4-channel relay which is shown by glowing LED which is in front of second channel and also the sprinkling method is displayed in LCD for driver's knowledge. In **Figure 11(c)**, gravity sprinkling is actuated by sending a signal to the third channel of a 4-channel relay which is shown by glowing LED which is in front of third channel and also the sprinkling method is displayed in LCD for driver's knowledge. In **Figure 11(d)**, MIST sprinkling is actuated by sending a signal to the fourth channel of a 4-channel relay which is shown by glowing LED which is in front of fourth channel and also the sprinkling method is displayed in LCD for driver's knowledge.

Conclusions

The requirements based on the problem statement were that the system should monitor the density of fine dust particles which are contained in air borne particles in mine and accordingly module has to actuate the sprinkling operation. The proposed solution is capable to continuously monitor the dust present in the mine environment and automatically actuate the sprinkling operation based on the dust density calculated. The developed system has several advantages like easy to use functionality, cost-effectiveness, real-time communication, compact in size and hence reduces the large space occupation in vehicle, reduces human intervention thus increases accuracy of the system and also reduces wastage of water. The designed module is a good and inexpensive solution to the requirements mentioned and this module is being tested and approved for implementation in the water sprinkler manufactured at BEML in order to automate the water sprinkler.

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